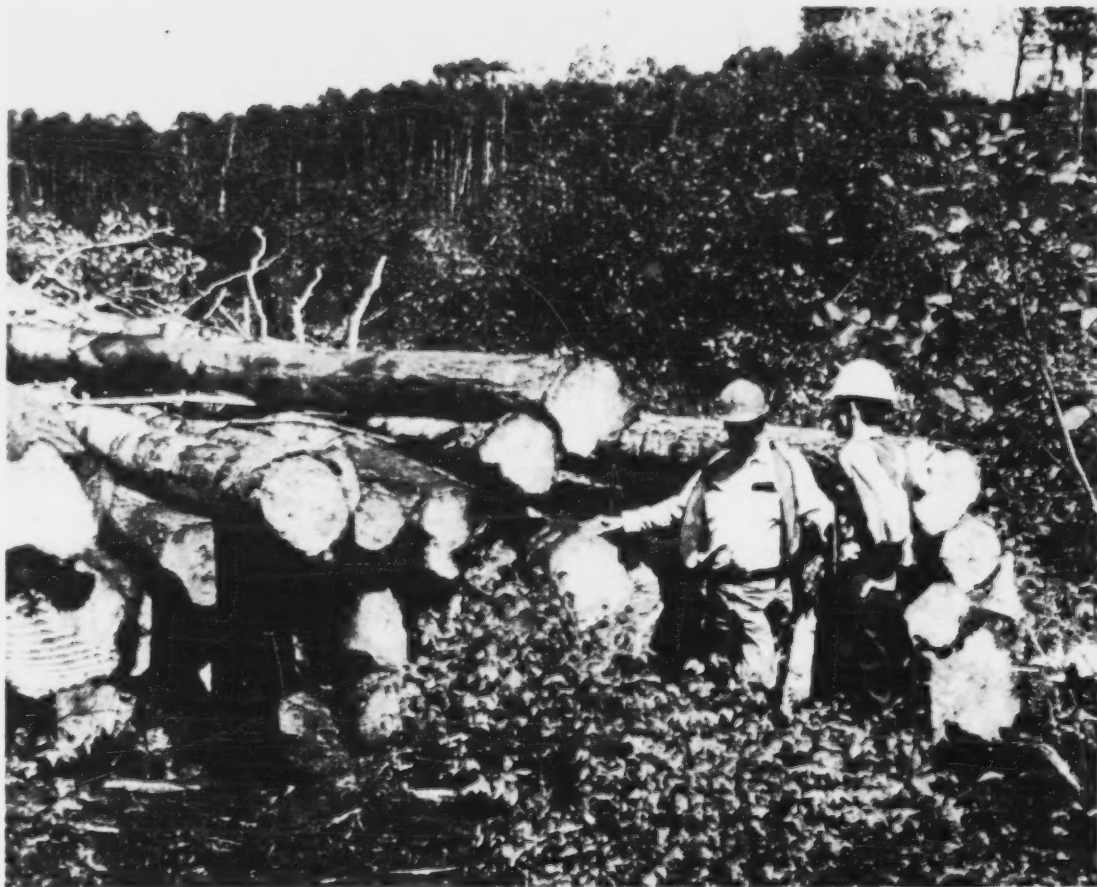


Developing Sustainable Mixedwood Practices in a Stand-Level Adaptive Management (SLAM) Framework: Project Establishment



Developing Sustainable Mixedwood Practices in a Stand-Level Adaptive Management (SLAM) Framework: Project Establishment

by

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Abstract

Forest managers in Ontario need reliable guidelines for promoting desirable species mixtures to enhance economic and ecological diversity. The objective of this project is to advance knowledge of boreal mixedwood (BMW) management by testing techniques for achieving productive mixtures of conifers and hardwoods at operational scales. Treatments are being applied in aspen-dominated BMW stands on the limits of Abitibi-Consolidated Inc. and Domtar Inc. in northeastern Ontario. Contrasting approaches are being compared (blended mixtures vs. mosaics, partial cutting vs. herbicide application, shade-tolerant vs. shade-intolerant conifer regeneration) to help identify best practices. Treatment effectiveness will be assessed by measuring regeneration growth, vegetation succession, soil nutrient dynamics, and changes in invertebrate populations. Operational feasibility will be evaluated by estimating costs for all elements of the treatments. The project plan is based on the active adaptive management (AAM) steps of *assess, design, implement, monitor, evaluate, and adjust*. Government, industry, non-profit, and academic partners have made long-term commitments and accepted clearly defined roles related to the AAM framework for this project. Knowledge gained will be transferred using techniques matched to the needs of specific client groups (policymakers, forest managers, the science community, and the public) and recommendations on applying AAM in forestry will be developed. Since this project will be implemented in an adaptive management framework that emphasizes practical application, incorporating the results into provincial silvicultural guidelines and forest management plans will be a high priority. This report provides an overview of study sites and methodologies.

Acknowledgements

The Living Legacy Trust, the Ontario Ministry of Natural Resources (OMNR), Abitibi-Consolidated Inc., and Domtar Inc. are providing funding for this project. Sault College is contributing equipment for field and laboratory work. OMNR, the Forest Engineering Research Institute of Canada, and the Canadian Forest Service are providing scientific direction. The Upper Lakes Environmental Research Network (ULERN) is currently serving as project administrator. OMNR, ULERN, and the Lake Abitibi Model Forest are facilitating communication among partners. The authors appreciate technical assistance from M. Beaudoin, D. Niblett, S. Stuart, and S. Wawryszyn, graphics support from T. Vaitinen, and reviews of an earlier draft by B. Cole and A. Obenchain.

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Background

Boreal Mixedwood Information Needs

Deliberately managing for appropriate mixtures of species has been advocated in North America (Brace Forest Services 1992, Irland and Maass 1994, Lieffers and Beck 1994, MacDonald 1995) and northern Europe (Bradshaw and Gemmel 1992, Norokorpi 1992, Parviainen 1994, Björse and Bradshaw 1998) to enhance economic and ecological diversity. Progress in developing mixedwood management techniques has been reported for some regions of Canada. For example, in Quebec, boreal mixedwood silvicultural techniques based on natural ecosystem dynamics have been proposed (Bergeron and Harvey 1997), and in western Canada, practices to promote mixtures of trembling aspen (*Populus tremuloides* Michx.) and white spruce (*Picea glauca* [Moench] Voss) have been tested (Samoil 1988, Shorttreid 1991, Lieffers and Beck 1994, Navratil 1996, Ball and Walker 1997, MacIsaac et al. 1999).

In northwestern Ontario, the Black Sturgeon boreal mixedwood (BMW) project was designed to provide comprehensive information on mixedwood responses to various harvesting practices (Scarratt et al. 1996). Unfortunately, the experiment was largely destroyed by wildfire shortly after establishment. In northeastern Ontario, other smaller-scale experiments have helped identify potential harvesting and regeneration options for BMW stands (Groot 1999, MacDonald 2000, MacDonald and Thompson 2003). However, additional understanding is required to adequately address issues relevant to Ontario resource managers at operational scales. These issues include economic and ecological benefits of species mixtures compared with single-species stands, costs of producing species mixtures, optimum spatial patterns for hardwood and conifer components, and options for reducing herbicide use.

An improved understanding of successional patterns following various forest disturbances would provide a reliable basis for sequencing crop species rotations or preparing measures to counter succession of non-crop species. However, little quantitative information on BMW successional patterns exists (Kenkel et al. 1998). Since light level is an important driver of vegetation dynamics and crop tree performance on mixedwood sites (Messier 1996, Comeau 2001), the relationship between

light regime and vegetation abundance and diversity should be studied to gain insights into successional dynamics following mixedwood management.

Biodiversity maintenance and soil conservation are other important aspects of sustainable BMW management. For example, forest management can alter soil structure (Ballard 2000, Fox 2000) and function (Bell et al. 1996, Johnson et al. 1996, Trettin et al. 1996, McLaughlin et al. 2000, Prescott et al. 2000), which may affect site productivity. Relationships between specific mixedwood management practices and compaction, rutting, nutrient dynamics, carbon storage, and soil biodiversity need to be quantified to help evaluate the sustainability of these practices.

Active Adaptive Management: A Useful Framework

Passive adaptive management is promoted in Ontario's forest management planning process (OMNR 1996). Managers using this approach implement a single preferred silvicultural treatment package (STP) in appropriate forest units and document the effects to improve STPs in subsequent management plans. In contrast, managers using active adaptive management (AAM) implement several alternative STPs simultaneously to identify the best management option, using a sequence of 6 steps: *assess, design, implement, monitor, evaluate, and adjust* (Figure 1). The active, experimental approach yields more reliable information and leads to more rapid understanding (Taylor et al. 1997).

The AAM approach has been applied to natural resource management in various regions of North America (Rempel et al. 1997, Stankey and Shindler 1997, Taylor et al. 1997, MacDonald et al. 1999). Since the reported initiatives emphasize the technical, economic, and institutional obstacles to AAM, guidelines are needed to incorporate it into forest management plans in Ontario.

Project Origins

The rationale for developing an operational-scale adaptive management project addressing forestry issues was derived from recommendations in a feasibility study (MacDonald et al. 1997) and a conference on the topic (MacDonald et al. 1999). Representatives of government,

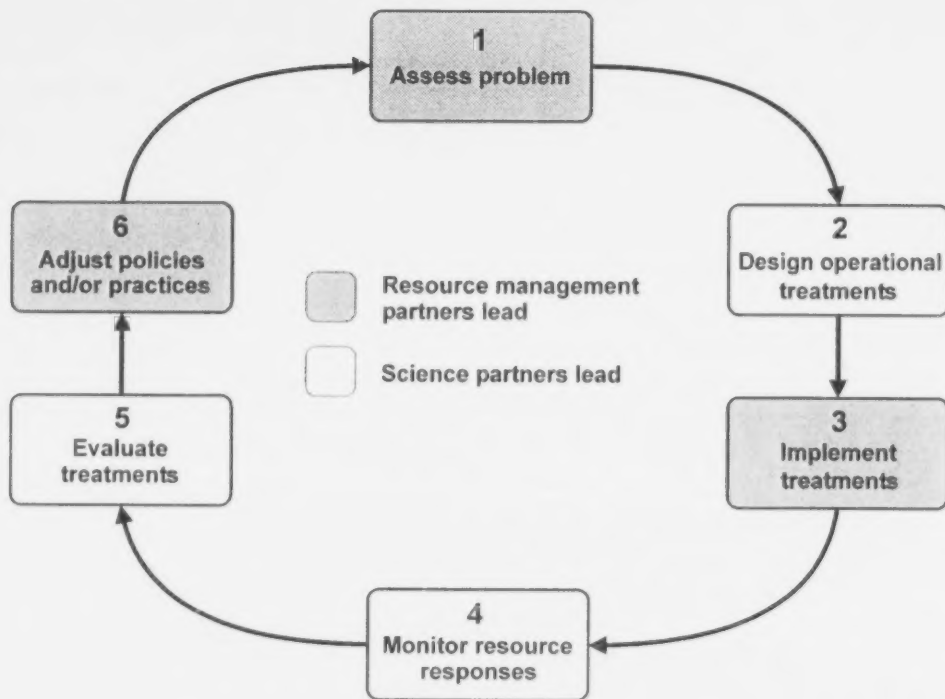


Figure 1. Steps in the active adaptive management cycle and roles of partners in this project.

industry, non-profit, and academic organizations developed a formal partnership to plan and implement the project. A workshop was conducted for partners and external experts to define the most limiting management uncertainties, formulate potential management scenarios (treatment packages), propose indicators for assessing treatment responses, and define partner roles and responsibilities.

Objectives

The main objective of this project is to evaluate alternative approaches for regenerating productive and balanced mixtures of conifers and hardwoods on BMW sites in Ontario. The following questions are being addressed:

1. Does managing for conifer-hardwood mixtures increase total volume yield compared with managing for conifer plantations?
2. Does conifer regeneration in mixed stands attain better survival, height growth, and quality in blended mixtures or in mosaics of alternating conifer and hardwood patches?
3. How effective is partial cutting compared with herbicide application for enhancing survival, height

growth, and quality of conifer regeneration in BMW stands?

4. How do operational costs compare for blended mixtures, mosaics, and pure conifer plantations?
5. How do ecological indicators (e.g., vegetation succession, microclimate, soil properties, and invertebrate populations) compare for blended mixtures, mosaics, and pure conifer plantations?
6. What are baseline values of abundance and diversity for bioindicator invertebrate species in BMW stands?
7. What measures of vegetation, microclimate, soil processes, and biodiversity can be integrated to produce a reliable indicator of ecological sustainability on managed BMW sites?

Treatment responses will need to be monitored for at least 10 years to develop reliable answers for most of these questions. However, some questions (e.g., 4 and 6 above) may be addressed within the first 2 years.

Since an adaptive management framework is being used, a secondary objective is to document the barriers and bridges to implementing AAM and to develop recommendations for applying AAM in forestry.

Project Partners

Partners include the Ontario Ministry of Natural Resources (OMNR), the Canadian Forest Service (CFS), the Forest Engineering Research Institute of Canada (FERIC), Abitibi-Consolidated Inc., Domtar Inc., the Lake Abitibi Model Forest, the Upper Lakes Environmental Research Network, and Sault College of Applied Arts and Technology. The roles of partnering organizations are outlined in Table 1. Fulfillment of complementary roles by all partners will ensure new knowledge is generated and implemented according to the AAM cycle (Figure 1). The diversity of partners enhances the relevance of objectives and approaches and leverages valuable support from participating agencies.

Partners and collaborators are contributing cash, staff time, specialized skills, facilities, and equipment. Industry's in-kind contributions include modifying conventional harvesting and silvicultural practices to accommodate the experimental design, signifying a strong commitment to the adaptive management framework. The participation of industrial partners with different market orientations and management objectives (i.e., desirable species mixtures) will broaden the applicability of the results.

The research partners (OMNR, CFS, and FERIC) are responsible for developing scientifically sound methods, acquiring resources, and implementing their sub-studies according to an integrated plan. All participants are following mutually acceptable protocols for site access and data collection to minimize sample plot disturbance.

An advisory committee has been established to help develop relevant treatments and review draft project outputs. Members include representatives of CFS, Université du Québec à Montréal, and OMNR's Forest Management Branch, Applied Research and Development Branch, and Northeast Science and Information Section.

Site Descriptions

Accessible treatment sites supporting mature BMW stands were identified in the Abitibi-Consolidated Iroquois Falls Forest and the Domtar Spanish Forest (Figure 2). Uniform species composition was required to permit treatment replication using 16- to 20-ha experimental units, with at least 20% aspen stocking in the overstory to ensure hardwood regeneration.



Figure 2. Locations of the boreal mixedwood stands used for establishing the treatment plots in this project.

The Abitibi-Consolidated treatment site is located in a single cutblock (48°47' N, 80°15' W) (Figure 3). The Domtar site is divided into 2 cutblocks approximately 3 km apart (47°30' N, 81°57' W and 47°30' N, 82°00' W) (Figure 4). Pre-harvest measurements were conducted at both sites, as described below. Initial stand characteristics are summarized in tables 2 to 4, and ecosite occurrence is summarized in Table 5.

Site class estimates indicate good growth potential for conifers and hardwoods at both sites (Table 4). Based on maximum tree ages, sampled stands likely originated from wildfires in 1920 at the Abitibi-Consolidated site and 1900 at the Domtar site. Jack pine (*Pinus banksiana* Lamb.) became established first, followed by trembling aspen and white birch (*Betula papyrifera* Marsh.) within a few years. Most white spruce and balsam fir (*Abies balsamea* [L.] Mill.) became established within 10 years of the pioneer species at the Abitibi-Consolidated site and within 20 years at the Domtar site. Black spruce (*Picea mariana* [Mill.] B.S.P.) occurred as part of this youngest cohort at the Domtar site but at the Abitibi-Consolidated site it consisted primarily of scattered dominant trees that predated the wildfire. The higher stocking of understory hardwoods at the Domtar site (Table 3) reflects the greater age of the original stand, which was characterized by canopy gaps suitable for hardwood development.

Initially, these 2 sites will be used to test mixedwood management options and refine the process of applying AAM to forestry issues. More studies will be required to

Table 1. Roles of partner organizations in this project.

Organization	Role
Ontario Ministry of Natural Resources	Lead silviculture, succession, and soils components; develop experimental design and coordinate its implementation; manage project database; maintain website; produce newsletter articles, technical reports, and journal papers; conduct tours
Canadian Forest Service	Lead biodiversity component (invertebrate populations); produce technical reports and journal papers
Forest Engineering Research Institute of Canada	Compare costs and productivity among treatments; produce technical reports
Abitibi-Consolidated and Domtar	Implement harvesting and renewal treatments according to experimental design and provincial silvicultural guidelines; maintain access; monitor free-to-grow status of conifer regeneration; adjust management plans based on project results; conduct tours
Lake Abitibi Model Forest	Lead marketing, training, and education; liaise with local stakeholders (First Nations, industrial, educational, recreational, and municipal organizations); link to national Model Forest Network; produce newsletters; arrange tours
Upper Lakes Environmental Research Network	Oversee project management, financial tracking, partnership agreements, and communication and reporting to funding agencies
Sault College	Incorporate new information into course curricula; share field equipment through Canada Foundation for Innovation (CFI) and Ontario Innovation Trust (OIT) grants

Table 2. Summary of pre-treatment overstory basal area estimates, based on systematic sampling of each site in 2001 and 2002.

Site	Conifer ¹ basal area (m ² ha ⁻¹)				Hardwood ² basal area (m ² ha ⁻¹)			
	Merchantable ³		Unmerchantable ⁴		Merchantable ³		Unmerchantable ⁴	
	Mean	SD ⁵	Mean	SD	Mean	SD	Mean	SD
Abitibi	6.32	7.62	0.20	0.71	27.41	12.25	0.27	0.83
Domtar	6.36	7.68	0.39	1.40	17.58	10.46	1.85	2.94

¹Conifers occurring on at least 1 site included jack pine, black spruce, white spruce, and balsam fir.

²Hardwoods occurring on at least 1 site included trembling aspen and white birch.

³Living trees ≥ 10 cm DBH.

⁴Living trees < 10 cm DBH.

⁵Standard deviation.

test whether results can be applied to other mixedwood ecosites in northern Ontario.

Design Overview

The 6 main steps of the AAM cycle are summarized in Figure 1. By consulting with resource managers and other experts, the partners have addressed steps 1 and 2 (*assessing* the mixedwood management problems and *designing* treatments and experimental approaches). Steps 3 and 4 (*implementing* the mixedwood treatments and *monitoring* the responses of key indicators) are the primary focus of this

report. The partners are committed to maintaining this project over the long term to ensure that steps 5 and 6 (*evaluating* the effectiveness of the mixedwood treatments and *adjusting* provincial guidelines and company management plans) are completed.

Although AAM projects require sound experimental designs, they favour operational relevance over scientific protocols (Nyberg 1998, Sit and Taylor 1998). All treatments in this project are being implemented with standard industrial equipment and are incorporated into the planning and operations of Abitibi-Consolidated

(Iroquois Falls Forest) and Domtar (Spanish Forest). The experience gained at each step of the AAM cycle will be documented, and recommendations will be made for applying adaptive management to forestry issues.

AAM treatments should go beyond incremental changes to existing practices and use strong actions that create contrasting responses to hasten learning (Peternan 1999). While acknowledging this need, the partners realized that treatments must be operationally and economically feasible. For example, many forest companies in northern Ontario prefer a single-pass approach that completes extraction and regeneration within a 5-year period. This approach minimizes costs associated with long-term road maintenance and equipment transportation. Furthermore, regeneration techniques should have a high chance of success because companies want to return treated areas to the inventory by meeting regeneration standards as rapidly as possible. As a result, clearcut and shelterwood systems with artificial regeneration are being used in this project.

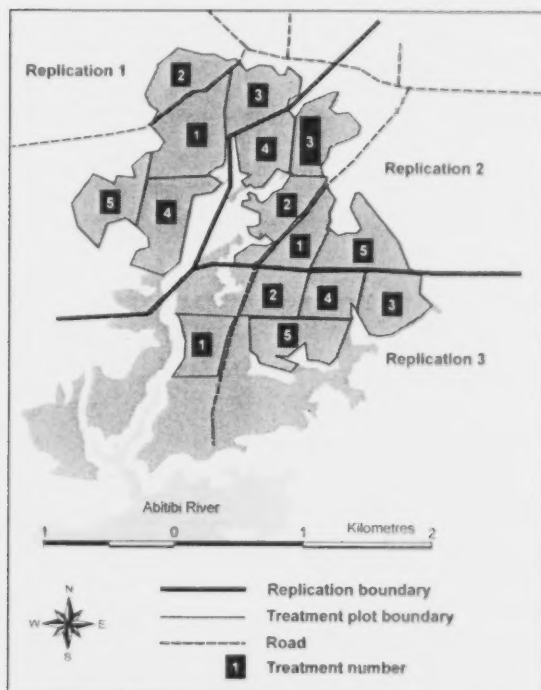


Figure 3. Layout of treatment plots within 3 replications at the Abitibi-Consolidated site. The treatments are: 1) blended mixture of conifers and hardwoods, 2) mosaic of alternating conifer and hardwood corridors, 3) corridor mosaic with partial cutting, 4) conifer plantation (silvicultural control), and 5) uncut reference stand.

Table 3. Summary of pre-treatment understory stocking¹ estimates, based on systematic sampling of each site in 2001 and 2002.

Site	Conifer ² stocking %		Hardwood ³ stocking %	
	Mean	SD ⁴	Mean	SD
Abitibi-Consolidated	21.76	22.27	1.67	4.40
Domtar	21.91	19.62	54.76	29.34

¹Percentage of 2 m x 2 m sample plots containing at least 1 crop tree less than 1.3 m tall.

²Conifers occurring on at least 1 site included jack pine, black spruce, white spruce, and balsam fir.

³Hardwoods occurring on at least 1 site included trembling aspen and white birch.

⁴Standard deviation.

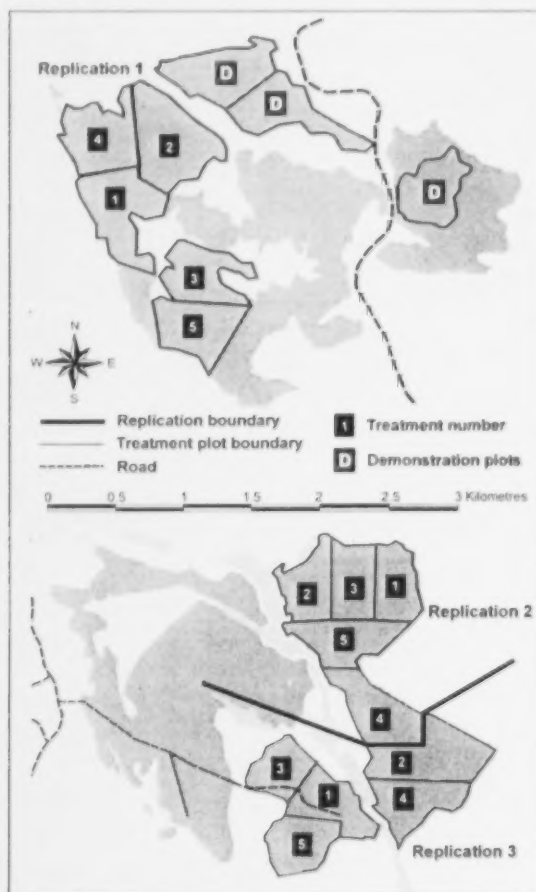


Figure 4. Layout of treatment plots within 3 replications at the Domtar site. The experimental site is divided into 2 cutblocks at the same latitude, with replication 1 approximately 3 km east of replications 2 and 3. The treatments are: 1) blended mixture of conifers and hardwoods, 2) mosaic of alternating conifer and hardwood corridors, 3) corridor mosaic with partial cutting, 4) conifer plantation (silvicultural control), and 5) uncut reference stand.

Table 4. Summary of pre-treatment characteristics of individual inventory species at the 2 treatment sites, based on sampling 3 to 5 trees per species in each treatment plot.

Species	N	Height (m)		Age (years)		DBH ¹ (cm)		SC ³
		Mean	SD ²	Mean	SD	Mean	SD	
<i>Abitibi-Consolidated</i>								
Jack pine	13	25.1	3.1	75.9	5.4	32.2	5.1	1
Black spruce	2	28.6	13.0	80.5	0.7	20.7	2.9	1a
White spruce	17	23.1	4.0	64.2	11.3	37.3	9.9	-
Balsam fir	6	21.2	2.9	67.7	6.2	25.8	4.1	-
Trembling aspen	47	26.2	1.9	72.8	5.5	39.0	6.2	1
White birch	15	22.0	2.1	73.9	6.1	28.5	6.1	1
<i>Domtar</i>								
Jack pine	44	24.2	2.2	83.8	13.1	37.3	5.9	1
Black spruce	20	16.8	2.5	63.8	17.6	23.2	4.9	1a
White spruce	60	20.3	4.2	63.4	21.1	35.6	9.7	-
Balsam fir	19	17.2	2.2	59.4	16.0	23.4	3.4	-
Trembling aspen	51	24.7	3.2	81.8	16.0	36.6	6.6	2
White birch	41	20.7	2.4	81.4	15.3	28.5	6.2	1

¹Presence of heart height, 1.3 m above ground.

²Standard deviation.

³One class based on height age classes: 0-10 years (10-15 cm) for young spruce and fir; 10-20 years (16-25 cm) for mature spruce and fir; 20-30 years (26-35 cm) for old spruce and fir.

Table 5. Habitat types¹ distribution of each site based on sampling 1 to 3 HX² sample plots in each treatment plot in 2002. Domtar replication 1 is listed separately because it is located 3 km from replications 2 and 3.

Site	Ecosite type ²						
	3	6c	7f	7m	7c	10	11
Abitibi-Consolidated	1	1	31	-	-	7	-
Domtar (rep 1)	2	-	-	-	6	-	-
Domtar (reps 2 and 3)	-	-	-	17	-	-	1

¹Abbreviated names based on site, habitat type, and species.

²Legend for site types:

3c White Birch - Trembling Aspen - Black Spruce - Balsam Fir

6c Trembling Aspen - Black Spruce - Balsam Fir - Balsam Fir

7f Trembling Aspen - White Spruce - White Birch - Balsam Fir

7m Trembling Aspen - White Spruce - White Birch - Balsam Fir

7c Trembling Aspen - White Birch - Balsam Fir

10 Trembling Aspen - White Birch - Balsam Fir

11 Trembling Aspen - Black Spruce - Balsam Fir - Balsam Fir

12 Black Spruce - Trembling Aspen - Balsam Fir

13 Black Spruce - Trembling Aspen - Balsam Fir

14 Black Spruce

The treatments build on approaches used in western Canada (Nayral 1996, Ball and Walker 1997), while answering questions relevant to resource managers in Ontario. To increase the likelihood of identifying best mixedwood practices, contrasting approaches are being compared: blended mixtures vs. mosaics, partial cutting vs. herbicide application, shade-tolerant vs. shade-intolerant conifer regeneration. Specifically, the following treatments are being implemented:

1. Blended mixture of conifers and hardwoods.

This treatment includes aerially spraying the aspen overstory with glyphosate (1.05 kg ha⁻¹ acid equivalent) prior to harvesting to reduce but not eliminate post-harvest aspen suckering, clearcutting with standards,

mechanically site preparing the entire treatment area, and planting 1500 conifers per hectare between site preparation windows.

2. Mosaic of alternating conifer and hardwood corridors.

This treatment involves clearcutting with standards (travelling along 10-m wide harvested corridors allocated to conifer regeneration, which alternate with 10-m wide untravelled but harvested corridors allocated to hardwood regeneration), mechanically site preparing and planting 1500 seedlings per hectare in the conifer corridors, and aerially spraying the conifer corridors with glyphosate (1.75 and 1.40 kg ha⁻¹ acid equivalent for Abitibi-Consolidated and Domtar, respectively) after the second growing season. Successive harvests (50- to 60-

Table 4. Summary of pre-treatment characteristics of individual overstory species at the 2 treatment sites, based on sampling 3 to 5 trees per species in each treatment plot.

Species	N	Height (m)		Age (years)		DBH ¹ (cm)		SC ³
		Mean	SD ²	Mean	SD	Mean	SD	
Abitibi-Consolidated								
Jack pine	13	25.1	3.1	75.9	5.4	32.2	5.1	1
Black spruce	2	28.6	13.0	80.5	0.7	20.7	2.9	1a
White spruce	17	23.1	4.0	64.2	11.3	37.3	9.9	-
Balsam fir	6	21.2	2.9	67.7	6.2	25.8	4.1	-
Trembling aspen	47	26.2	1.9	72.8	5.5	39.0	6.2	1
White birch	15	22.0	2.1	73.9	6.1	28.5	6.1	1
Domtar								
Jack pine	44	24.2	2.2	83.8	13.1	37.3	5.9	1
Black spruce	20	16.8	2.5	63.8	17.6	23.2	4.9	1a
White spruce	60	20.3	4.2	63.4	21.1	35.6	9.7	-
Balsam fir	19	17.2	2.2	59.4	16.0	23.4	3.4	-
Trembling aspen	51	24.7	3.2	81.8	16.0	36.6	6.6	2
White birch	41	20.7	2.4	81.4	15.3	28.5	6.2	1

¹Diameter at breast height (1.3 m above ground).

²Standard deviation.

³Site class, based on height-age curves of Plonski (1974); curves not published for white spruce and balsam fir.

Table 5. Ecosite frequency distribution at each site, based on sampling 1 to 3 FEC¹ sample plots in each treatment plot in 2002. Domtar replication 1 is listed separately because it is located 3 km from replications 2 and 3.

Site	Ecosite type ²							
	3	6c	7f	7m	7c	10	11	15
Abitibi-Consolidated	1	1	31	-	-	7	-	-
Domtar (rep 1)	2	-	-	-	6	-	-	-
Domtar (reps 2 and 3)	-	-	-	17	-	-	1	1

¹Northeastern Ontario forest ecosite classification (Taylor et al. 2000).

²Names of ecosite types:

3: White Birch – Trembling Aspen – Black Spruce – Coarse Soil

6c: Trembling Aspen – Black Spruce – Jack Pine – Coarse Soil

7f: Trembling Aspen – White Spruce – White Birch – Fine Soil

7m: Trembling Aspen – White Birch – Medium Soil

7c: Trembling Aspen – White Birch – Coarse Soil

10: Trembling Aspen – Black Spruce – Balsam Poplar – Moist Soil

11: Black Spruce – Labrador Tea – Organic Soil

15: Red Maple

The treatments build on approaches used in western Canada (Navratil 1996, Ball and Walker 1997), while answering questions relevant to resource managers in Ontario. To increase the likelihood of identifying best mixedwood practices, contrasting approaches are being compared (blended mixtures vs. mosaics, partial cutting vs. herbicide application, shade-tolerant vs. shade-intolerant conifer regeneration). Specifically, the following treatments are being implemented:

1. Blended mixture of conifers and hardwoods.

This treatment includes aerially spraying the aspen overstory with glyphosate (1.05 kg ha⁻¹ acid equivalent) prior to harvesting to reduce but not eliminate post-harvest aspen suckering, clearcutting with standards,

mechanically site preparing the entire treatment area, and planting 1500 conifers per hectare between site preparation windrows.

2. Mosaic of alternating conifer and hardwood corridors.

This treatment involves clearcutting with standards (travelling along 10-m-wide harvested corridors allocated to conifer regeneration, which alternate with 10-m-wide untravelled but harvested corridors allocated to hardwood regeneration), mechanically site preparing and planting 1500 seedlings per hectare in the conifer corridors, and aerially spraying the conifer corridors with glyphosate (1.75 and 1.40 kg ha⁻¹ acid equivalent for Abitibi-Consolidated and Domtar, respectively) after the second growing season. Successive harvests (50- to 60-

year intervals) may alternate between: (1) travelling along hardwood corridors and clearcutting only hardwoods, with no site preparation or planting and (2) travelling along conifer corridors, clearcutting the entire stand, and site preparing and planting the conifer corridors. The conifer and hardwood corridors are permanently defined and are oriented north-south if possible to minimize wind damage following subsequent harvest entries and to equalize solar radiation across the regenerating conifer corridors.

3. Corridor mosaic with partial cutting. This treatment reduces overall basal area (BA) by an average of 50%, travelling along 10-m-wide harvested corridors allocated to conifer regeneration, which alternate with 10-m-wide untravelled and unharvested corridors that are allocated to hardwoods. The conifer corridors are mechanically site prepared and planted with 1500 seedlings per hectare. This approach differs from Treatment 2 by adding partial cutting for the initial entry to inhibit aspen suckering, as an alternative to herbicide spraying. It is included to acknowledge the trend towards restrictions on herbicide application in Canada. Residual hardwood corridors will be harvested approximately 5 years after the initial cut, when planted conifers are tall enough to compete with aspen suckers.

4. Conifer plantation (silvicultural control). This conventional treatment involves clearcutting with standards, mechanically site preparing, planting conifers according to standard prescriptions (1800 to 2500 trees ha⁻¹), and aerially spraying with glyphosate (1.75 and 1.40 kg ha⁻¹ acid equivalent for Abitibi-Consolidated and Domtar, respectively) after the second growing season.

5. Uncut reference stand. No silvicultural treatments are applied.

The treatments were designed to create stand structures and compositions that accommodate subsequent harvest entries to perpetuate mixedwood management. A dual rotation system may be required to manage mixed stands of species with contrasting silvics and growth rates, such as white spruce and trembling aspen. The corridor mosaic pattern allows either a single rotation system (harvesting conifers and hardwoods every 70 to 80 years) or a dual rotation system (alternating every 50 to 60 years between harvesting only hardwoods and harvesting both conifers and hardwoods).

Equipment and scheduling specifications for the treatments are summarized in Table 6. Both sites were full-tree harvested with feller-bunchers during the 2002-03 dormant period. The Domtar site preparation and planting schedule will follow the Abitibi-Consolidated schedule by 1 growing season. Using blade scarification is supported by evidence of its cost-effectiveness and success in limiting competing vegetation when establishing mixed spruce-aspen stands (Archibold et al. 2000).

Seedlings will be planted at approximately 2.0 m x 2.7 m spacing in the blended mixture treatment and 2.0 m x 2.0 m in the corridor mosaic treatment. Since only travelled corridors will be planted in the corridor mosaic treatment, both treatments will result in 1500 seedlings per hectare. To meet future mill requirements, white spruce will be planted on the Abitibi-Consolidated site and jack pine on the Domtar site. Comparing results from the 2 sites will provide information on whether shade-tolerant white spruce or shade-intolerant jack pine regenerates more successfully under each mixedwood management strategy tested.

Pre-Harvest Measurements

Pre-harvest assessments in 2001 and 2002 provided data to guide treatment plot location and characterize initial conditions, respectively. Data from 2001 that coincided with the 2002 sampling areas were included for characterizing stand conditions (Table 7). Knowledge of initial stand conditions was used to define the inference population to which the results apply and confirm the appropriateness of planned regeneration prescriptions. For example, low stocking of conifer advance growth (Table 3) indicated the need for artificial regeneration.

In 2001, coordinates of temporary sample points at 200 m x 100 m spacing were located in the field using a global positioning system. On the Abitibi-Consolidated site, spacing was widened to 300 m x 100 m for the northern 75% of the survey area to ensure the inventory could be completed while crews were available. The following variables were recorded at every sample point: overstory BA by species and status (living merchantable, living unmerchantable, or dead), using a prism swing; number of understory trees on a 2 m x 2 m sample plot, by species and height class (15.0 to 49.9 cm, 50.0 to 129.9 cm, and >130.0 cm but < 2.5 cm diameter at breast height [DBH]); and percent cover of shrubs on the same sample plot.

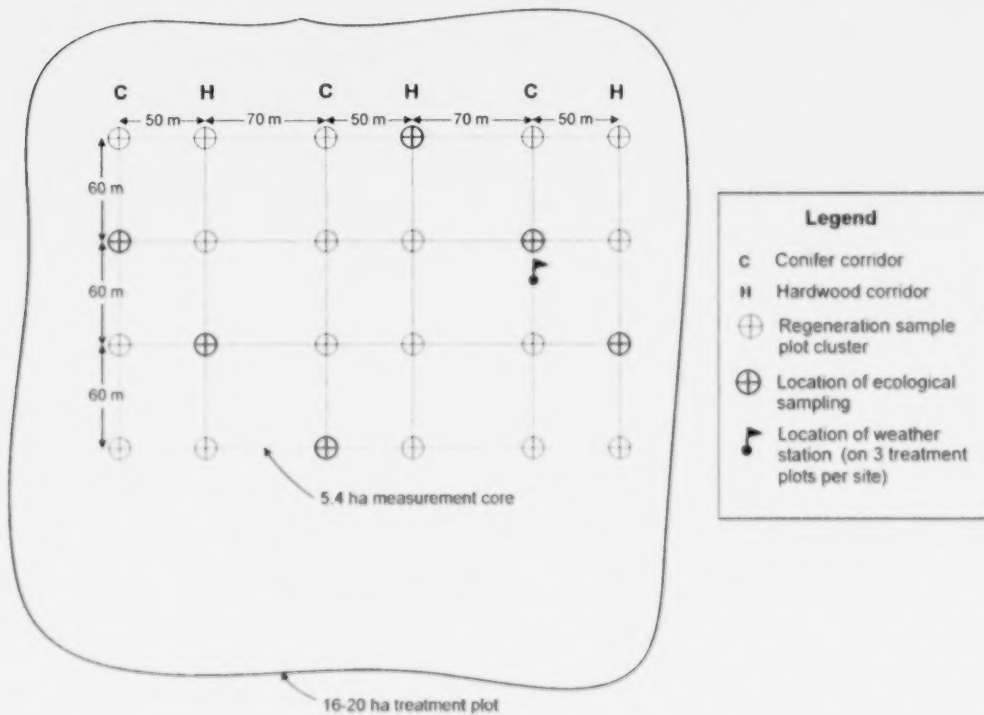


Figure 5. Layout of regeneration sample plots within a corridor mosaic treatment plot. Topographic features and operational deviations from the prescriptions cause the distances between sampling corridors to vary from those shown.

At every second sample point on the Domtar site (i.e., at 200 m x 200 m spacing), an auger was used to obtain samples of the predominant soil at 60-cm depth (actual depth was recorded if bedrock was encountered). Soil texture was assessed (Taylor et al. 2000) to identify gradients within the study area that could provide a basis for laying out treatment replications.

Since treatment plot boundaries were known prior to the 2002 field season, measurements in 2002 were conducted within these boundaries to approximate future sampling locations. Permanent sample plots could not be used for pre-treatment measurements because locations of planting corridors (and hence locations of post-treatment permanent sample plots) were unknown prior to harvesting and site preparation. The information described for the 2001 assessment was also collected in 2002, at approximately 6 well-spaced sampling points per treatment plot. In addition, hemispherical photographs of the canopy were taken above and below the shrub layer at the 6 sampling points (see *Post-Harvest Measurements* section for description of methods), and the

DBH, height, and age of 3 to 5 trees for each overstory species were measured within each treatment plot (not confined to the 6 sampling points). Vegetation types, soil types, and ecosite types were determined according to the northeastern Ontario forest ecosystem classification (Taylor et al. 2000) in 1 to 3 sample plots per treatment plot.

Plot Layout

Treatment Plots

Treatments were randomly allocated to main plots (experimental units) in 3 blocks (replications) at each site. Since soil texture is generally uniform, blocks were designed to stratify the level of overstory aspen BA, which is an indicator of suckering potential. Based on proposed road locations and data from the 2001 survey, boundary coordinates of treatment plots were defined to guide treatment implementation. Treatment plots range in size from 16 to 20 ha, with shapes determined by topographical features and road locations (figures 3 and 4). In stand-level silvicultural trials, especially those using

Table 6. *Equipment/material specifications and scheduling for treatment implementation.*

Treatment component	Abitibi-Consolidated		Domtar	
	Equipment/material	Scheduling	Equipment/material	Scheduling
Pre-harvest herbicide application on aspen overstory (treatment 1)	1.05 kg ha ⁻¹ glyphosate by fixed-wing biplane	August 2002	1.05 kg ha ⁻¹ glyphosate by helicopter	August 2002
Harvesting	John Deere 853G feller-buncher	August to November 2002	Timberjack 850 feller-buncher	October 2002 to March 2003
Skidding	Trans-Gesco TG-88B clambunk skidder with high-flotation tracks	August to November 2002	Timberjack 560 grapple skidder	October 2002 to March 2003
Site preparation	Caterpillar D-8 tractor with Rome K/G 3.6-m shear blade	February 2003	Caterpillar D-8 tractor with angle blade	September 2003
Planting	White spruce overwintered container stock	May to June 2003	Jack pine overwintered container stock	May to June 2004
Post-planting herbicide application (treatments 2 and 4)	1.75 kg ha ⁻¹ glyphosate by fixed-wing biplane	August 2004	1.40 kg ha ⁻¹ glyphosate by helicopter	August 2005

an adaptive management framework, large plots are important to ensure results are relevant at the scale of normal forest operations.

Sample Plots

Locations of permanent sample plots will be staked and tagged after site preparation is complete. Grids of 24 clusters of 4 permanent sample plots will be established in all treatment plots except for the uncut reference stands, which will have only the 6 clusters required for ecological measurements (see below). Ideally, sample plot clusters will be spaced approximately 60 m x 60 m in a 5.4-ha interior measurement core, leaving a treated buffer at least 40 m wide (Figure 5). Systematic sampling at this intensity is normal company procedure for regeneration assessments. However, some measurement cores may be compressed to avoid access roads, landings, and slash piles. If the contiguously treated area is insufficient to accommodate all 24 sample plot clusters, measurement cores may be divided into 2 sections.

In the corridor mosaic treatments, spacing will be varied to place sample plot clusters in alternating conifer and hardwood corridors as close as possible to 60-m spacing. Six corridors will be sampled, with 4 sample plots established at 45- to 60-m intervals within each corridor. In the blended mixture treatment, where conifer and hardwood corridors are less distinctly defined, a 60 m x 60 m spacing of sample plot clusters will be attempted. Sample plots will not be established on windrows between site-prepared strips.

Responses of crop-tree regeneration will be measured on all 24 sample plot clusters, but cost will limit the number of ecological sample plot clusters to 6 per treatment plot (Figure 5). Each ecological cluster will have a surrounding triangular transect for assessing downed woody debris (DWD) (Domtar site only), an adjacent sample point for measuring overstory BA by prism swing, another sample point for obtaining hemispherical canopy photographs, and a 10 m x 10 m sample plot for monitoring soil variables (Figure 6). In each treatment plot at the Abitibi-Consolidated site, a separate sampling

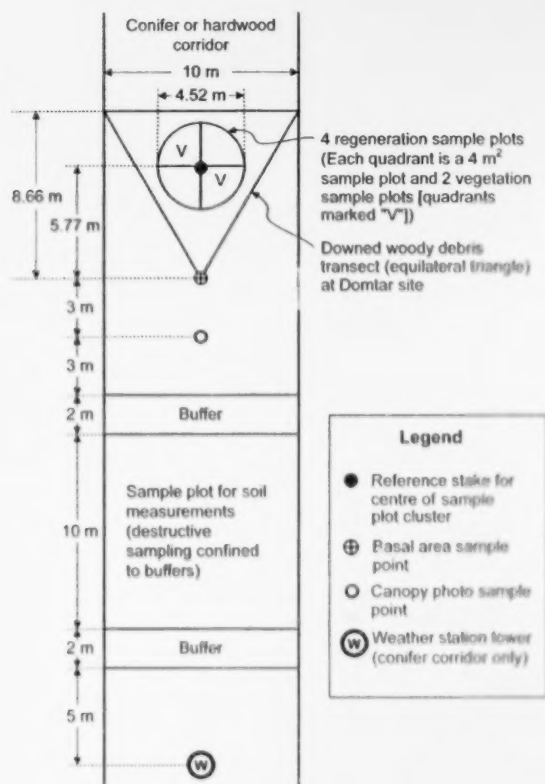


Figure 6. Layout of one cluster of regeneration sample plots and ecological sample points and plots in a corridor mosaic treatment.

grid will be used to measure invertebrate populations. Uncut reference stands will have only ecological sample plot clusters, since no regeneration treatments will be conducted in those stands.

Systematically selecting ecological sample plot clusters ensures sample plots are dispersed across the treatment plots. It also places 3 sample plot clusters in conifer corridors and 3 in hardwood corridors, allowing sample plot means to be calculated for both conifer and hardwood responses.

Post-Harvest Measurements

Overstory

The ecological sample plots will be used to measure residual overstory trees and crop tree regeneration >2.5 cm DBH. The following variables will be measured for living and dead trees counted by prism swing: species, status (living or dead), origin (natural or planted), DBH, crown

class, damage extent, and decay class (snags only). The BA per hectare for each species will also be recorded. Height information will be obtained from local height-diameter curves, supplemented by data from the pre-harvest survey. Based on the outcome of post-harvest inspections, damage to residuals from logging and wind may be sampled more intensively on partially cut plots (treatment 3).

Regeneration

The following variables will be measured for crop tree regeneration >10.0 cm tall in the 4 sample plots in all 24 clusters: species, status (living or dead), height, and damage extent. Stem counts will be obtained for living crop trees <10.0 cm tall. After harvesting, aspen suckers >2.5 cm DBH will be measured on the regeneration sample plots rather than by overstory prism swings until the sucker density falls below 10,000 stems ha^{-1} .

Vegetation Succession

To assess changes in understory vegetation abundance and diversity, the following variables will be measured on 2 of the 4 sample plots at each ecological sample plot cluster (Figure 6): percent cover of trees, shrubs, annual flowering plants, ferns, grasses and sedges, and mosses and number of trees, shrubs, and annual flowering plants, by species. To fully evaluate treatment effects on understory communities, a wide range of plant forms needs to be included. For example, Newmaster and Bell (2002) reported that silvicultural treatments affect cryptogam (spore producer) richness and abundance.

Soils

At the Abitibi-Consolidated site, soil measurements will include above- and belowground elemental pools, litter inputs and decomposition, and nutrient cycling and leaching. Lateral water movement may also be measured because this movement could be an important aspect of nutrient dynamics in the fine-textured soils at the Abitibi-Consolidated site. These measurements will be used to determine the impacts of BMW management on nutrient dynamics and carbon pools. To limit costs, only extensive measurements will be taken at the Domtar site (Table 8). At both sites, soils will be sampled at all 6 ecological sample plot clusters in the corridor mosaic treatments but at only 3 of the clusters in the remaining treatments and uncut reference stands. Soil temperature will be measured continuously by data logger in 1 sample plot in each

treatment plot and uncut stand, except for corridor mosaic treatment plots, where conifer and hardwood corridors will both be sampled. These data will be supplemented by monthly measurements of soil temperature (thermocouples) and soil moisture (gravimetric) on all sample plots.

Coarse Woody Debris

Coarse woody debris (CWD), which comprises standing dead trees (snags) and DWD, is an important indicator of habitat quality. Data on snags will be captured in the overstory measurements. At the Abitibi-Consolidated site, DWD will be measured using a total tally on the soil sample plot (Table 8). At the Domtar site, DWD will be measured on transects at the 6 ecological sample plot clusters per treatment plot, using a modified version of published survey methods (Van Wagner 1968, McRae et al. 1979, Van Wagner 1980, Hely et al. 2000). A sample will comprise 3 10-m transects laid out as an equilateral triangle (Figure 6). The triangular design reduces orientation bias in DWD positioning. Species, category (log or stump), diameter, and decomposition class will be recorded for DWD that is intersected by a transect and is greater than 7.5 cm in diameter at the intersection point.

Biodiversity

Biodiversity sampling will be conducted only at the Abitibi-Consolidated site. Invertebrates will be used as indicators because changes in populations occur at small temporal and spatial scales and should reveal effects of mixedwood management within a short time frame and a small geographic area. Ground beetles and spiders are readily identified, can be sampled in sufficient numbers to draw meaningful conclusions, have a stable taxonomy, and are good indicators of disturbance in forested landscapes (Hulita 1971, Beaudry et al. 1997, Duchesne et al. 1999). Saproxyllic beetles depend on decaying wood or associated fungi for survival and may be affected by altered CWD dynamics associated with harvesting activities. They may be important indicators of changes in decomposition and nutrient cycling processes (Hammond 1997).

Carabid beetles, ground spiders, and saproxyllic beetles will be sampled for approximately 100 days from May through August. Ground-dwelling invertebrates (carabids

Table 7. Distribution of systematically located sample plots used for characterizing pre-harvest conditions.

Site	Number of sample plots			
	Overstory ¹		Understory ²	
	2001 ³	2002	2001 ³	2002
Abitibi-Consolidated	18	93	18	93
Domtar	13	111	3	111

¹Sample plots based on variable-radius prism using

²2 m x 2 m sample plot

³Sample plots measured in 2001 were included for characterizing pre-harvest conditions only if they coincided with the 2002 sampling areas.

and spiders) will be sampled using 48 pitfall traps per treatment plot, arranged in a grid covering the same measurement core as the 24 sample plot clusters used for regeneration assessments. Traps will be centred in conifer or hardwood corridors to optimize the buffer width. They consist of a 1.0-L plastic cup inside a section of PVC pipe. The top will be set flush with the soil surface and covered with a plastic plate suspended 1 cm above the trap. Propylene glycol in the traps will immobilize and preserve the invertebrates. A 1-m radius around each trap will be sampled for microhabitat characteristics (moisture, ground cover, litter type and depth). Saproxyllic beetles will be sampled using 9 flight-intercept traps per treatment plot on 1 treatment replication. All traps will be emptied biweekly, and the invertebrates washed, sorted, and stored in 75% ethanol. Target beetle and spider families will be identified to the species level.

Hemispherical Photographs of Canopy Cover

Canopy photographs will be taken at a fixed sample point at each ecological sample plot cluster (Figure 6). Photographs will be taken at 50 and 400 cm above ground to assess light levels below and above the shrub layer, respectively. Light level will be quantified by gap fraction, canopy openness, leaf area index, and light transmission index. These variables will be derived from digitized hemispherical canopy photographs using Gap Light Analyzer image analysis software (Frazer et al. 1999).

Microclimate

In the spring of 2003, Hobo[®] weather stations (Onset Computer Corporation, Bourne, MA) will be installed in 1

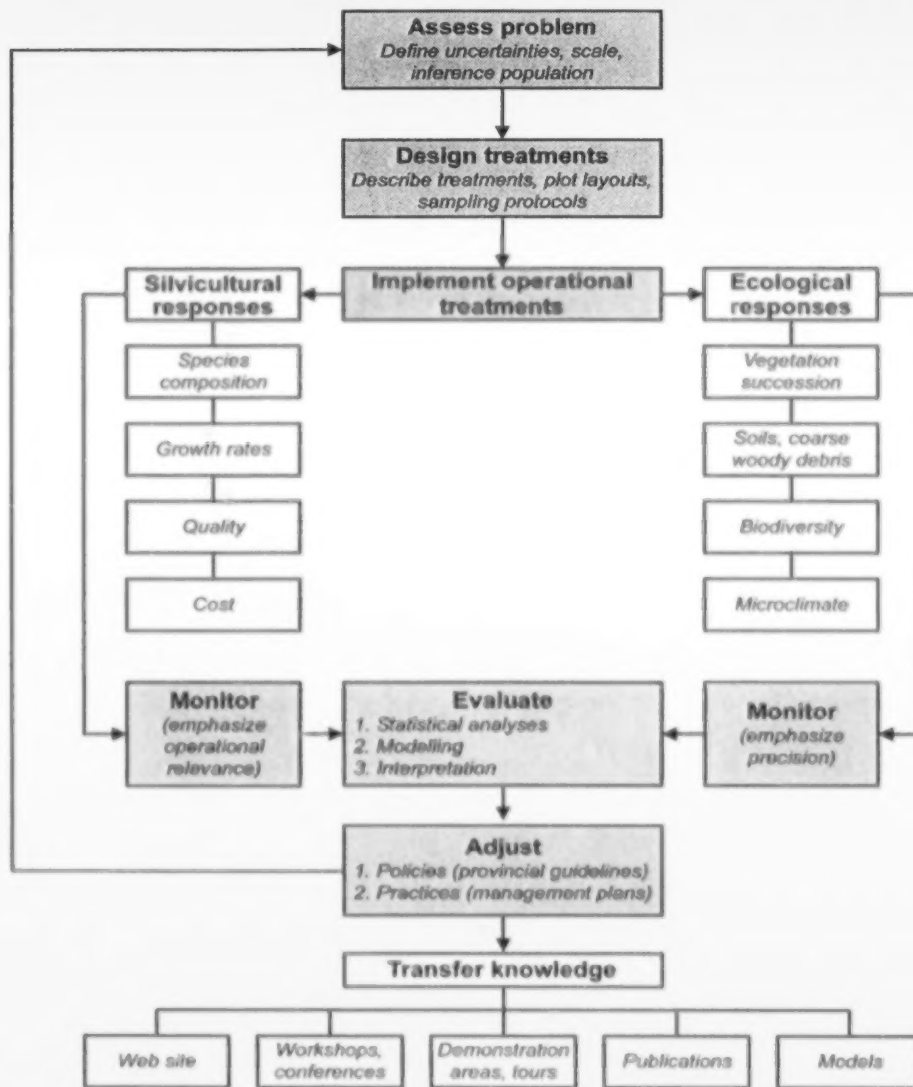


Figure 7. Overview of project components. The main steps in the active adaptive management cycle are shaded.

replication of treatments 1, 3, and 5 at each site, adjacent to ecological sample plots (figures 5 and 6). Data loggers will record values annually from June through September for the following variables: air temperature, humidity, soil temperature, soil moisture, photosynthetically active radiation (PAR), wind speed and direction, and precipitation. PAR will be measured at 5-second intervals, and all variables will be logged at 10-minute intervals. Since cost prevents microclimatic measurements on all replications, the data will be used for description rather than statistical inference. The data will also help generate hypotheses about the relationship

between environmental factors and the selected response indicators.

Economic Evaluation

Economic indicators are important because cost will determine how extensively the treatments can be applied in regular forest operations. Economic feasibility will be evaluated by estimating typical costs for all treatment elements. Existing models and interviews with operations staff will be used to determine generic costs for delimbing, site preparation, planting, and herbicide spraying. Feller-buncher and skidder productivity will be

Table 8. Silvicultural and ecological response variables measured.

Variables	Measurement intensity	Protocol references
Regeneration Responses (Abitibi-Consolidated and Domtar)		
Species, height, damage assessment for all crop tree regeneration	24 clusters of 4 sample plots per treatment plot (2304 samples)	Sampling intensity used by companies
Stand Structure and Vegetation Succession (Abitibi-Consolidated and Domtar)		
Stand basal area; tree origin, diameter at breast height, crown class, damage assessment, and snag decay class, by species	6 variable-radius prism plots per treatment plot (180 samples)	Hayden et al. (1995)
Vegetation succession: Abundance, diversity, percent cover, density by species	12 sample plots per treatment plot (360 samples)	Hayden et al. (1995)
Canopy Closure and Light Regime (Abitibi-Consolidated and Domtar)		
Gap fraction, canopy openness, leaf area index, light transmission index	6 sample points per treatment plot at 2 heights (50 and 400 cm) (360 samples)	Lieffers et al. (1999)
Microclimate (Abitibi-Consolidated and Domtar)		
Air temperature, relative humidity, soil temperature, soil moisture, photosynthetically active radiation, wind speed and direction, precipitation	3 microclimate stations per site, supplemented by continuous soil temperature monitoring in 1 sample plot treatment, monthly soil temperature measurement on all sample plots, and monthly gravimetric soil moisture measurement on all plots	Jones (1992)
Soils (Abitibi-Consolidated and Domtar)		
Total carbon, nitrogen, phosphorus, calcium, magnesium, potassium, exchangeable calcium, magnesium, potassium	2 samples per horizon per year at 6 sample plots per treatment plot (1080 samples)	Fernandez et al. (1995)
Aggregate stability	As above	Kemper and Rosenau (1982)
Porosity and pore size distribution	As above	Danielson and Sutherland (1982)
Bulk density	As above	Blake and Hartge (1982)
Particle-size distribution	As above	Gee and Bauder (1982)
Nitrogen mineralization	2 samples per horizon per month at 6 sample plots per treatment plot (6480 samples)	McLaughlin et al. (2000)
Above- and Belowground Woody Debris and Litter (Abitibi-Consolidated only)		
Carbon, nitrogen, phosphorus, calcium, magnesium, potassium in foliage, branches, and stems	5 samples per year at 6 sample plots per treatment plot (450 samples)	Bledsoe et al. (1999), Harmon et al. (1999)
Aboveground total litter input	4 samples per month at 6 sample plots per treatment plot (2160 samples)	Bledsoe et al. (1999)
Foliar litter decomposition	As for aboveground litter input	Harmon et al. (1999)
Belowground litter input (root turnover)	As for aboveground litter input	Harmon et al. (1999)
Belowground woody debris decomposition	As for aboveground litter input	Harmon et al. (1999), McLaughlin and Jurgensen (2003)
Volume, density, biomass, and elemental content of snags, logs, and roots	Depending on number per sample plot	Harmon et al. (1999), Laiho and Prescott (1999)
Woody debris decay class	Depending on number per sample plot	Hayden et al. (1995), Duval and Grigal (1999)
Soil Solution Sampling (Abitibi-Consolidated only)		
Organic horizon leaching	2 samples per month at 6 sample plots per treatment plot (1080 samples)	Fernandez et al. (1995)
Leaching below root zone	As above	DiStefano and Gholz (1986), McLaughlin et al. (1996)
Biodiversity (Abitibi-Consolidated only)		
Ground invertebrates, moisture, ground cover, litter type and depth	48 pitfall traps per treatment plot (720 samples)	Spence and Niemela (1994)
Saproxyllic beetles (flying)	9 flight intercept traps per treatment plot on 1 replication (45 samples)	Chenier and Philogene (1989), de Groot and Knott (2001)

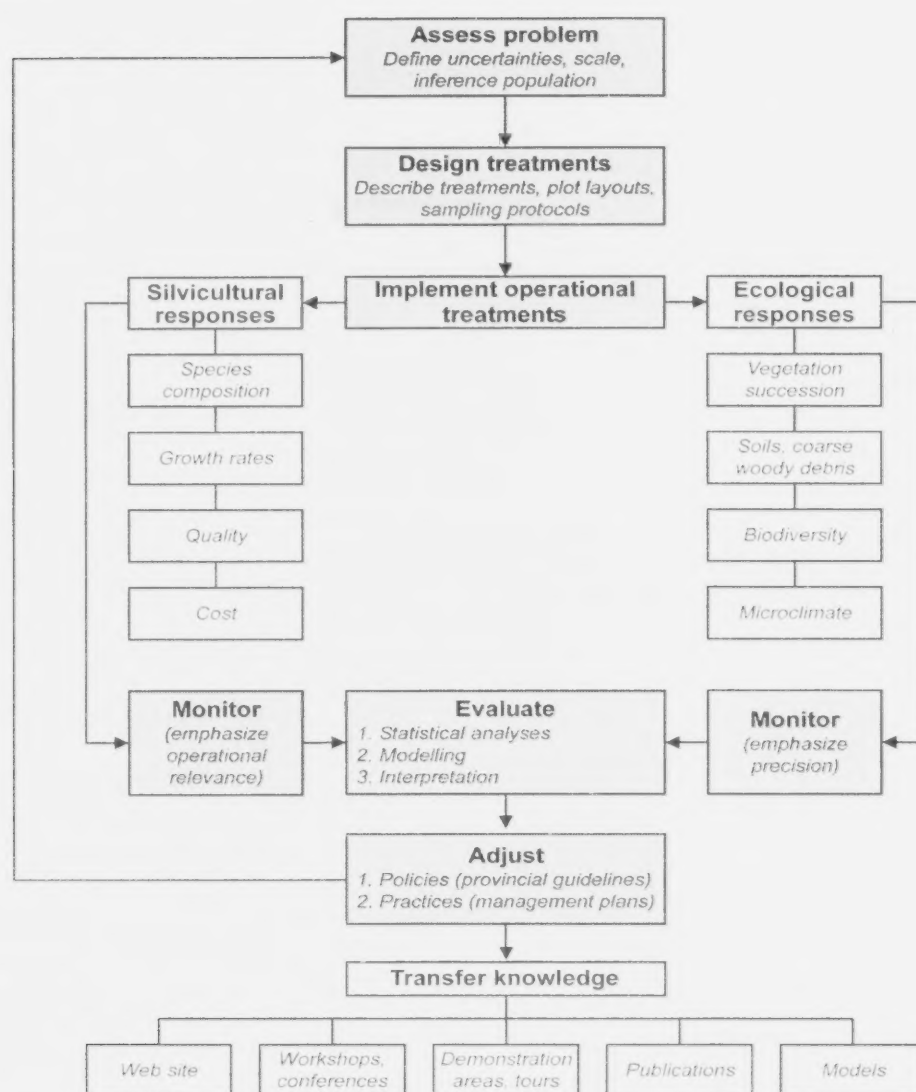


Figure 7. Overview of project components. The main steps in the active adaptive management cycle are shaded.

replication of treatments 1, 3, and 5 at each site, adjacent to ecological sample plots (figures 5 and 6). Data loggers will record values annually from June through September for the following variables: air temperature, humidity, soil temperature, soil moisture, photosynthetically active radiation (PAR), wind speed and direction, and precipitation. PAR will be measured at 5-second intervals, and all variables will be logged at 10-minute intervals. Since cost prevents microclimate measurements on all replicates, the data will be used for description rather than statistical inference. The data will also help generate hypotheses about the relationship

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Economic indicators are important because cost will determine how extensively the treatments can be applied in regular forest operations. Economic feasibility will be evaluated by estimating typical costs for all treatment elements. Existing models and interviews with operations staff will be used to determine generic costs for delimbing, site preparation, planting, and herbicide spraying. Feller-buncher and skidder productivity will be

Table 8. *Subcultural and ecological response variables measured.*

Variables	Measurement intensity	Protocol references
Regeneration Responses (Abitibi-Consolidated and Domtar)		
Species, height, damage assessment for all crop tree regeneration	24 clusters of 4 sample plots per treatment plot (2304 samples)	Sampling intensity used by companies
Stand Structure and Vegetation Succession (Abitibi-Consolidated and Domtar)		
Stand basal area, tree origin, diameter at breast height, crown class, damage assessment, and snag decay class, by species	6 variable-radius prism plots per treatment plot (180 samples)	Hayden et al. (1995)
Vegetation succession, Abundance, diversity, percent cover, density by species	12 sample plots per treatment plot (360 samples)	Hayden et al. (1995)
Canopy Closure and Light Regime (Abitibi-Consolidated and Domtar)		
Gap fraction, canopy openness, leaf area index, light transmission index	6 sample points per treatment plot at 2 heights (50 and 400 cm) (360 samples)	Lieffers et al. (1999)
Microclimate (Abitibi-Consolidated and Domtar)		
Air temperature, relative humidity, soil temperature, soil moisture, photosynthetically active radiation, wind speed and direction, precipitation	3 microclimate stations per site, supplemented by continuous soil temperature monitoring in 1 sample plot treatment, monthly soil temperature measurement on all sample plots, and monthly gravimetric soil moisture measurement on all plots	Jones (1992)
Soils (Abitibi-Consolidated and Domtar)		
Total carbon, nitrogen, phosphorus, calcium, magnesium, potassium, exchangeable calcium, magnesium, potassium	2 samples per horizon per year at 6 sample plots per treatment plot (1080 samples)	Fernandez et al. (1995)
Aggregate stability	As above	Kemper and Rosenau (1982)
Porosity and pore size distribution	As above	Danielson and Sutherland (1982)
Bulk density	As above	Blake and Hartge (1982)
Particle-size distribution	As above	Gee and Bauder (1982)
Nitrogen mineralization	2 samples per horizon per month at 6 sample plots per treatment plot (6480 samples)	McLaughlin et al. (2000)
Above- and Belowground Woody Debris and Litter (Abitibi-Consolidated only)		
Carbon, nitrogen, phosphorus, calcium, magnesium, potassium in foliage, branches, and stems	5 samples per year at 6 sample plots per treatment plot (450 samples)	Bledsoe et al. (1999) Harmon et al. (1999)
Aboveground total litter input	4 samples per month at 6 sample plots per treatment plot (2160 samples)	Bledsoe et al. (1999)
Foliar litter decomposition	As for aboveground litter input	Harmon et al. (1999)
Belowground litter input (root turnover)	As for aboveground litter input	Harmon et al. (1999)
Belowground woody debris decomposition	As for aboveground litter input	Harmon et al. (1999) McLaughlin and Jurgensen (2003)
Volume, density, biomass, and elemental content of snags, logs, and roots	Depending on number per sample plot	Harmon et al. (1999) Laiho and Prescott (1999)
Woody debris decay class	Depending on number per sample plot	Hayden et al. (1995) Duvall and Grigal (1999)
Soil Solution Sampling (Abitibi-Consolidated only)		
Organic horizon leaching	2 samples per month at 6 sample plots per treatment plot (1080 samples)	Fernandez et al. (1995)
Leaching below root zone	As above	DiStefano and Gholz (1986) McLaughlin et al. (1996)
Biodiversity (Abitibi-Consolidated only)		
Ground invertebrates, moisture, ground cover, litter type and depth	48 pitfall traps per treatment plot (720 samples)	Spence and Niemela (1994)
Saproxylous beetles (flying)	9 flight intercept traps per treatment plot on 1 replication (45 samples)	Chenier and Philogene (1989) de Groot and Knott (2001)

compared between partially cut and clearcut treatments, using detailed timing studies and appropriate scaling procedures. This comparison will permit adjustment of generic productivity models.

Measurement Schedule

Silvicultural and ecological response variables (Table 8) will be measured annually during the first 5 years after treatment, then at 2- to 3-year intervals during the following 10 to 20 years. The industry partners will monitor seedling free-growing status for 5 to 7 years. These operational assessments will be compared with more detailed measurements by research crews to determine the level of data resolution required for decisionmaking in an adaptive management framework. Economic indicators will be measured only during treatment implementation.

At the Abitibi-Consolidated site, all the above post-harvest measurements will be obtained in 2003. At the Domtar site, the full set of post-harvest measurements (excluding the biodiversity component) will begin in 2004, after site preparation and planting. In 2003, measurements on the Domtar site will include: (1) a repeat of the 2002 pre-harvest sampling of overstory BA, regeneration, and shrubs (6 points per treatment plot), (2) ground cover of herbaceous vegetation at the same points, (3) hemispherical canopy photographs (50 and 400 cm above ground) at the same points, (4) a repeat of the pre-harvest regeneration sampling on an additional 96 sample plots (24 circular clusters of 4 4-m² sample plots) in treatments 1 and 4, to assess the effects of pre-harvest spraying on aspen regeneration, and (5) microclimatic variables recorded on weather stations installed near their estimated future permanent locations on 1 replication of treatments 1, 3, and 5.

Data Analysis and Treatment Evaluation

Regeneration responses at fixed times after treatment will be analyzed by 1-way ANOVA and planned comparisons. When multi-year data are available, time series analyses will be conducted to test for differences in growth trajectories among treatments (Pitt et al. 1999). Descriptive statistics (e.g., diameter and volume frequency distributions) will be used to compare stand structures among treatments.

Mathematical models such as the Nutrient Cycling Model (Liu et al. 1992) and CENTURY 4.0 (Parton et al.

1987, Peng et al. 2000) will be used to predict soil nutrient cycling and carbon pools under different mixedwood management scenarios. Analysis of covariance will be used to test treatment effects on nitrogen mineralization; nutrient and carbon pools; soil chemistry; organic nitrogen, phosphorus, and carbon accumulation in the mineral soil; and litter decomposition. Multivariate regression will be used to evaluate relationships among soil chemistry, soil physical properties, nitrogen mineralization, soil temperature, and soil moisture.

The effects of microhabitat characteristics, CWD attributes, and BMW treatments on invertebrate species abundance will be tested using ANOVA or non-parametric equivalents. Relationships among microenvironmental conditions, treatments, and groups of invertebrate species (species assemblages) will be explored using multivariate ordination. Relationships between beetle populations and CWD will be quantified using linear regression, generating hypotheses on the role of beetles in nutrient cycling. Beetles are important facilitators of nutrient cycling (Edmonds and Eglitis 1989, Hammond et al. 2001), but the relationships have not been described for managed BMW stands.

Knowledge Transfer

Knowledge gained through this project will be transferred to forest managers, policymakers, the science community, and the public, using tools tailored to each client group. These tools include newsletter articles, technical reports, scientific papers, field tours, demonstration areas, technical meetings, facilitated workshops, conference presentations, project website, and linkages to academic institutions. All reports will be in the public domain and accessible on the website.

Linkages with developers and users of applied management planning models will be maintained. Long-term data from this project will help to calibrate the models for Ontario's BMW forests.

Transfer tools and other project components are summarized in Figure 7. Considering the AAM framework, a key measure of success will be the degree to which results are incorporated into new provincial silvicultural guidelines and forest management plans.

Challenges and Prospects

Adaptive management initiatives typically encounter political, institutional, economic, social, and technical obstacles (MacDonald et al. 1999). During its first 2 years, this project has faced challenges such as uncertain funding, changes in participating staff of partner organizations, and changes to forest company operating plans that have affected the experimental design. The partners have overcome these challenges by building consensus, sharing responsibilities, and factoring the need for flexibility into the experimental approach. The experience gained in this application of AAM will be reported in more detail in a separate publication.

Institutional, economic, and technical obstacles are anticipated as the project progresses, mainly during the implementation and monitoring steps of the adaptive management cycle. Training and supervising operational staff, keeping all partners focused on the goal of designed learning, and maintaining a balance between scientific protocols and operational realities will be ongoing challenges. However, the project objectives will likely be met because the partners are committed to the concept of continually improving BMW practices by linking science and resource management.

Literature Cited

- Archibald, O.W., C. Acton and E.A. Ripley. 2000. Effect of site preparation on soil properties and vegetation cover, and the growth and survival of white spruce (*Picea glauca*) seedlings, in Saskatchewan. *For. Ecol. Manage.* 131: 127-141.
- Ball, W.J. and N.R. Walker. 1997. Stand development after partial cutting of mature mixed stands of white spruce and aspen in Manitoba. *Can. For. Serv., North. For. Cent., Edmonton, AB. Inf. Rep. NOR-X-353*. 43 p.
- Ballard, T.M. 2000. Impacts of forest management of northern forest soils. *For. Ecol. Manage.* 133: 37-42.
- Beaudry, S., L.C. Duchesne and B. Côté. 1997. Short-term effects of three forestry practices on carabid assemblages in a jack pine forest. *Can. J. For. Res.* 27: 2065-2071.
- Bell, J.C., D.E. Grigal, P.C. Bates and C.A. Butler. 1996. Spatial patterns in carbon storage in a Lakes States landscape. Pp. 198-202 in Hom, J., R. Birdsey and K. O'Brian (eds.). *Proc. 1995 Meeting of the Northern Global Change Program*, Mar. 14-16, 1995, Pittsburgh, PA. USDA For. Serv., Radnor, PA. Gen. Tech. Rep. NE-214. 238 p.
- Bergeton, Y. and B. Harvey. 1997. Basing silviculture on natural ecosystem dynamics: An approach applied to the southern boreal mixedwoods of Québec. *For. Ecol. Manage.* 92: 235-242.
- Björse, G. and R. Bradshaw. 1998. 2000 years of forest dynamics in southern Sweden: Suggestions for forest management. *For. Ecol. Manage.* 104: 15-26.
- Blake, G.R. and K.H. Hartge. 1982. Bulk density. Pp. 363-376 in Klute, A. (ed.). *Methods of Soil Analysis. Part I. Physical and Mineralogical Methods*, 2nd ed. Soil Sci. Soc. Am., Madison, WI. 1159 p.
- Bledsoe, C.S., T.J. Fahey, F.P. Day and R.W. Ruess. 1999. Measurement of static root parameters. Pp. 413-436 in Robertson, G.P., D.C. Coleman, C.S. Bledsoe and P. Sollins (eds.). *Standard Soil Methods for Long-Term Ecological Research*. Oxford University Press, New York, NY. 462 p.
- Brace Forest Services. 1992. Protecting white spruce understories when harvesting aspen. *For. Can. and Alberta For. Serv., Edmonton, AB. Canada-Alberta Partnership Agreement in Forestry, Proj. No. 1480, Rep. No. 102*. 48 p.
- Bradshaw, R. and P. Gemmel. 1992. Diversity in systems of forest management - a southern Swedish perspective. Pp. 29-38 in Hagner, M. (ed.). *Silvicultural Alternatives*. Swedish Univ. Agric. Sci., Dep. Silviculture, Umeå, Sweden. Rep. No. 35. 214 p.
- Chenier, J.V.R. and B.J.R. Philogene. 1989. Evaluation of three trap designs for the capture of conifer feeding beetles and other forest Coleoptera. *Can. Entomol.* 121: 159-167.
- Comeau, P.G. 2001. Relationships between stand parameters and understory light in boreal aspen stands. *B.C. J. Ecosys. Manage.* 1: 1-8.
- Danielson, R.E. and P.E. Sutherland. 1982. Porosity. Pp. 443-462 in Klute, A. (ed.). *Methods of Soil Analysis. Part I. Physical and Mineralogical Methods*, 2nd ed. Soil Sci. Soc. Am., Madison, WI. 1159 p.
- de Groot, P. and R. Knott. 2001. Evaluation of traps of six different designs to capture pine sawyer beetles (Coleoptera: Cerambycidae). *Agric. For. Entomol.* 3: 107-111.
- DiStefano, J.F. and H.L. Gholz. 1986. A proposed use of ion exchange resins to measure nitrogen mineralization and nitrification in intact soil cores. *Commun. Soil Sci. Plant Anal.* 17: 989-999.
- Duchesne, L.C., R.A. Lautenschlager and F.W. Bell. 1999. Effects of clear-cutting and plant competition control methods on carabid (Coleoptera: Carabidae) assemblages in northwestern Ontario. *Environ. Monit. Assess.* 56: 87-96.
- Duvall, M.D. and D.E. Grigal. 1999. Effects of timber harvesting on coarse woody debris in red pine forests across the Great Lake States, U.S.A. *Can. J. For. Res.* 29: 1926-1934.
- Edmonds, R.L. and A. Eglitis. 1989. The role of the Douglas-fir beetle and wood borers in the decomposition of and nutrient release from Douglas-fir logs. *Can. J. For. Res.* 19: 853-859.
- Fernandez, I.J., L.E. Rustad, J.A. Simmons and J.W. McLaughlin. 1995. The Howland Integrated Forest Study (HIFS) - Ecosystem research on processes governing forest function. Pp. 298-306 in Jenkins, A., R.C. Ferrier and C. Kirby (eds.). *Ecosystem Manipulation Experiments: Scientific Approaches, Experimental Design, and Relevant Results*. Office for Official Publ. of the European Communities, Luxembourg, Belgium. *Ecosys. Res. Rep. No. 20*. 374 p.

- Fox, T.R. 2000. Sustained productivity in intensively managed forest plantations. *For. Ecol. Manage.* 138: 187-200.
- Frazer, G.W., C.D. Canham, P. Sallaway and D. Marinakis. 1999. Gap Light Analyzer, v. 2.0.4. Imaging software to extract forest canopy structure and gap light transmission indices from true-color hemispherical photographs. Simon Fraser University, Burnaby, British Columbia, and Institute of Ecosystem Studies, Millbrook, New York. Online software. <http://www.rem.sfu.ca/forestry/downloads/gap_light_analyzer.htm>. Accessed September 2003.
- Gee, G.W. and J.W. Bauder. 1982. Particle-size analysis. Pp. 383-412 in Klute, A. (ed.). *Methods of Soil Analysis. Part 1. Physical and Mineralogical Methods*, 2nd ed. Soil Sci. Soc. Am., Madison, WI. 1159 p.
- Groot, A. 1999. Effects of shelter and competition on the early growth of planted white spruce (*Picea glauca*). *Can. J. For. Res.* 29: 1002-1014.
- Hammond, H.E.J. 1997. Arthropod biodiversity from *Populus* coarse woody material in north-central Alberta: A review of taxa and collection methods. *Can. Entomol.* 129: 1009-1033.
- Hammond, H.E.J., D.W. Langor and J.R. Spence. 2001. Early colonization of *Populus* wood by saproxylic beetles (Coleoptera). *Can. J. For. Res.* 31: 1175-1183.
- Harmon, M.E., K.J. Nadelhoffer and J.M. Blair. 1999. Measuring decomposition, nutrient turnover, and stores in plant litter. Pp. 202-240 in Robertson, G.P., D.C. Coleman, C.S. Bledsoe and P. Sollins (eds.). *Standard Soil Methods for Long-Term Ecological Research*. Oxford University Press, New York, NY. 462 p.
- Hayden, J., J. Kerley, D. Carr, T. Kenedi and J. Hallarn. 1995. Ontario Forest Growth and Yield Program: Field manual for establishing and measuring permanent sample plots. Ont. Min. Nat. Resour., Ont. For. Res. Inst., Sault Ste. Marie, ON. 140 p.
- Hely, C., Y. Bergeron and M.D. Flannigan. 2000. Coarse woody debris in the southeastern Canadian boreal forest: Compositions and load variations in relation to stand replacement. *Can. J. For. Res.* 30: 674-68.
- Huhta, V. 1971. Succession in the spider communities of the forest floor after clear-cutting and prescribed burning. *Ann. Zool. Fenn.* 8: 483-542.
- Ireland, L.C. and D.I. Maass. 1994. Regional perspective: Forest conditions and silvicultural trends in the northeastern USA. *For. Chron.* 70: 273-278.
- Johnson, C.E., R.B. Romanowicz and T.G. Siccamo. 1996. Conservation of exchangeable cations after clear-cutting of a northern hardwood forest. *Can. J. For. Res.* 27: 859-868.
- Jones, H.G. 1992. *Plants and Microclimate*, 2nd ed. Cambridge Univ. Press, Cambridge, UK. 428 p.
- Kemper, W.D. and R.C. Rosenau. 1982. Aggregate stability and size distribution. Pp. 425-442 in Klute, A. (ed.). *Methods of Soil Analysis. Part 1. Physical and Mineralogical Methods*, 2nd ed. Soil Sci. Soc. Am., Madison, WI. 1159 p.
- Kenkel, N.C., P.R. Watson and P. Uhlig. 1998. Modelling landscape-level vegetation dynamics in the boreal forests of northwestern Ontario. Ont. Min. Nat. Resour., Ont. For. Res. Inst., Sault Ste. Marie, ON. For. Res. Rep. No. 148. 151 p.
- Laiho, R. and C.E. Prescott. 1999. The contribution of coarse woody debris to carbon, nitrogen, and phosphorus cycles in three Rocky Mountain coniferous forests. *Can. J. For. Res.* 29: 1592-1603.
- Lieffers, V.J. and J.A. Beck. 1994. A semi-natural approach to mixedwood management in the prairie provinces. *For. Chron.* 70: 260-264.
- Lieffers, V.J., C. Messier, K.J. Stadt, E. Gendron and P.G. Comeau. 1999. Predicting and managing light in the understory of boreal forests. *Can. J. For. Res.* 29: 796-811.
- Liu, S., R. Munson, D.W. Johnson, S. Gherini, K. Summers, R. Hudson, K. Wilkinsone and L.E. Pitelka. 1992. The Nutrient Cycling Model (NuCM): Overview and application. Pp. 583-609 in Johnson, D.W. and S.E. Lindberg (eds.). *Atmospheric Deposition and Forest Nutrient Cycling*. Springer-Verlag, New York, NY. 707 p.
- MacDonald, G.B. 2000. Harvesting boreal mixedwood stands to favour conifer regeneration: Project establishment and early results. Ont. Min. Nat. Resour., Ont. For. Res. Inst., Sault Ste. Marie, ON. For. Res. Rep. No. 157. 20 p.
- MacDonald, G.B. 1995. The case for boreal mixedwood management: An Ontario perspective. *For. Chron.* 71: 725-734.
- MacDonald, G.B. and D.J. Thompson. 2003. Responses of planted conifers and natural hardwood regeneration to harvesting, scalping, and weeding on a boreal mixedwood site. *For. Ecol. Manage.* 182: 213-230.
- MacDonald, G.B., R. Arnup and R.K. Jones. 1997. Adaptive forest management in Ontario: A literature review and strategic analysis. Ont. Min. Nat. Resour., Ont. For. Res. Inst., Sault Ste. Marie, ON. For. Res. Inf. Pap. No. 139. 38 p.
- MacDonald, G.B., J. Fraser and P. Gray. 1999. Adaptive management forum: Linking management and science to achieve ecological sustainability. Ont. Min. Nat. Resour., Sault Ste. Marie, ON. Sci. Dev. Transfer Ser. No. 001. 58 p.
- MacIsaac, D.A., S. Lux, D. Sidders and I. Edwards. 1999. Hotchkiss River mixedwood timber harvesting study. *For. Chron.* 75: 435-438.
- McLaughlin, J.W. and M.F. Jurgensen. 2003. Soil carbon variability in North American forests. USDA For. Serv., Rocky Mt. Res. Stn., Ogden, UT. Gen. Tech. Rep. (in press).
- McLaughlin, J.W., M.R. Gale, M.F. Jurgensen and C.C. Trettin. 2000. Soil organic matter and nitrogen cycling in response to harvesting, mechanical site preparation, and fertilization in a wetland with a mineral subsoil. *For. Ecol. Manage.* 129: 7-23.
- McLaughlin, J.W., G. Liu, M.F. Jurgensen and M.R. Gale. 1996. Organic carbon characteristics in a spruce swamp five years after harvesting. *Soil Sci. Soc. Am. J.* 60: 1228-1236.

- McRae D.J., M.E. Alexander and B.J. Stocks. 1979. Measurement and description of fuels and fire behaviour on prescribed burns: A handbook. Can. For. Serv., Sault Ste. Marie, ON. Inf. Rep. O-X-287. 44 p.
- Messier, C. 1996. Managing light and understorey vegetation in boreal and temperate broadleaf-conifer forests. Pp. 59-81 *in* Comeau, P.G. and K.D. Thomas (eds.). *Silviculture of Temperate and Boreal Broadleaf-Conifer Mixtures*. B.C. Min. For., Victoria, B.C. Land Manage. Handb. No. 36. 163 p.
- Navratil, S. 1996. Silvicultural systems for managing deciduous and mixedwood stands with white spruce understorey. Pp. 35-46 *in* Comeau, P.G. and K.D. Thomas (eds.). *Silviculture of Temperate and Boreal Broadleaf-Conifer Mixtures*. B.C. Min. For., Victoria, B.C. Land Manage. Handb. No. 36. 163 p.
- Newmaster, S.G. and F.W. Bell. 2002. The effects of silvicultural disturbances on cryptogam diversity in the boreal-mixedwood forest. *Can. J. For. Res.* 32: 38-51.
- Norokorpi, Y. 1992. Natural structure and development of forests as the basis for alternative silvicultural methods in northern Finland. Pp. 78-85 *in* Hagner, M. (ed.). *Silvicultural Alternatives*. Swedish Univ. Agric. Sci., Dep. Silviculture, Umea, Sweden. Rep. No. 35. 214 p.
- Nyberg, J. B. 1998. Statistics and the practice of adaptive management. Pp. 1-7 *in* Sit, V. and B. Taylor (eds.). *Statistical Methods for Adaptive Management Studies*. B.C. Min. For., Res. Br., Victoria, B.C. Land Manage. Handb. No. 42. 148 p.
- OMNR. 1996. Forest management planning manual for Ontario's Crown Forests. Ont. Min. Nat. Resour., For. Manage. Br., Sault Ste. Marie, ON. 452 p.
- Parton, W.J., D.S. Schimel, C.V. Cole and D.S. Ojima. 1987. Analysis of factors controlling soil organic matter levels in Great Plains grasslands. *Soil Sci. Soc. Am. J.* 51: 1173-1179.
- Parviainen, J. 1994. Finnish silviculture: Managing for timber production and conservation. *J. For.* 92: 33-36.
- Peng, C., J. Liu, M. Apps, Q. Dang and W. Kurz. 2000. Quantifying Ontario's forest carbon budget. 1. Carbon stocks and fluxes of forest ecosystems in 1990. Ont. Min. Nat. Resour., Ont. For. Res. Inst., Sault Ste. Marie, ON. For. Res. Rep. No. 158. 20 p.
- Peterson, R.M. 1999. The experimental approach in natural resource management. Pp. 3-5 *in* MacDonald, G.B., J. Fraser and P. Gray (eds.). *Adaptive management forum: Linking management and science to achieve ecological sustainability*. Ont. Min. Nat. Resour., Sault Ste. Marie, ON. Sci. Dev. Transfer Ser. No. 001. 58 p.
- Pitt, D.G., C. Stern Krishka, F.W. Bell and A. Lehele. 1999. Five-year performance of three conifer stock types on fine sandy loam soils treated with hexazinone. *N. J. Appl. For.* 16: 72-81.
- Plonski, W.L. 1974. Normal yield tables (metric) for major forest species of Ontario. Ont. Min. Nat. Resour., Div. For., Toronto, ON. 40 p.
- Prescott, C.E., D.G. Maynard and R. Laiho. 2000. Humus in northern forests: Friend or foe? *For. Ecol. Manage.* 133: 23-36.
- Rempel, R.S., P.C. Elkie, A.R. Rodgers and M.J. Gluck. 1997. Timber management and natural disturbance effects on moose habitat: Landscape evaluation. *J. Wildl. Manage.* 61: 517-524.
- Samoil, J.K. (ed.). 1988. Management and utilization of northern mixedwoods. Proc. symp. April 11-14, 1988, Edmonton, AB. Can. For. Serv., Edmonton, AB. Inf. Rep. NOR-X-296. 163 p.
- Scarratt, J.B., M. Johnston and B.J. Sutherland. 1996. The Black Sturgeon Boreal Mixedwood Research Project: Ecosystem research in support of integrated resource management. Pp. 202-207 *in* Smith, C.R. and G.W. Crook (comps.). *Advancing Boreal Mixedwood Management in Ontario*. Proc. Symp. October 17-19, 1995, Sault Ste. Marie, ON. Can. For. Serv., Sault Ste. Marie, ON. 239 p.
- Shorttreid, A. (ed.). 1991. Northern Mixedwood '89. Proc. symp. Sept. 12-14, 1989, Fort St. John, B.C. For. Can., Victoria, B.C. FRDA Rep. 164. 160 p.
- Sit, V. and B. Taylor. 1998. Statistical methods for adaptive management studies. B.C. Min. For., Res. Br., Victoria, B.C. Land Manage. Handb. No. 42. 148 p.
- Spence, J.R. and J.K. Niemela. 1994. Sampling carabid assemblages with pitfall traps: The madness and the method. *Can. Entomol.* 126: 881-894.
- Stankey, G.H. and B. Shindler. 1997. Adaptive management areas: Achieving the promise, avoiding the peril. USDA For. Serv., Portland, OR. Gen. Tech. Rep. PNW-GTR-394. 21 p.
- Taylor, B., L. Kremsater and R. Ellis. 1997. Adaptive management of forests in British Columbia. B.C. Min. For., Victoria, B.C. 93 p.
- Taylor, K.C., R.W. Arnup, B.G. Merchant, W.J. Parton and J. Nieppola. 2000. A field guide to forest ecosystems of northeastern Ontario, 2nd ed. Ont. Min. Nat. Resour., Timmins, ON. NEST Field Guide FG-001.
- Tretton, C.C., M. Davidian, M.F. Jurgensen and R. Lea. 1996. Organic matter decomposition following harvesting and site preparation of a forested wetland. *Soil Sci. Soc. Am. J.* 60: 1994-2003.
- Van Wagner, C.E. 1968. The line intersect method in forest fuel sampling. *For. Sci.* 14: 20-26.
- Van Wagner, C.E. 1980. Practical aspects of the line intersect method. Can. For. Serv., Petawawa, ON. Inf. Rep. PI-X-12. 11 p.

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